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Human Palatal Growth Evaluated on Medieval Crania Using Nerve Canal Openings as References

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ABSTRACT The purpose of this investigation was to measure postnatal lengthening and widening of the hard palate by use of nerve canal openings as references. The relationship of the dentition to the greater palatine foramina was also investigated.

Thirty-nine medieval dry skulls were examined, 22 from children and 17 from adults. All crania were photographed at a 1:1 scale. The dimensions of the maxilla and the location of the dentition were determined from the photographs.

The study showed that palatal growth in length in the sagittal plane takes place anterior to the greater palatine foramen. The growth increment in the area between the incisive foramen and the transverse palatine suture is more pronounced than the growth increment in the area between the transverse palatine suture and the greater palatine foramen. The distance from the greater palatine foramina to the posterior margin of the palate did not increase significantly with age. The growth in width seems to continue into adult life. The first permanent molars and the surrounding bone are moved forwards in relation to the greater palatine foramina during growth. The space for the developing maxillary premolars and molars therefore has to be obtained by growth in the transverse palatine suture.

Classical anthropological studies of the human palate are based on skeletal measurements of width and length, very often related to the development of the dentition (Brothwell, 1981). Orthodontic studies of measurements of the palate taken from study casts of growing children (Foster et al., 1977; Jakobsson, 1966; Klink-Heckmann and Piel, 1986; Lavelle, 1970; Masztalerz, 1988) have revealed the quantitative changes in the size of the palate during childhood. Radiological studies using the metal implants introduced by Björk (1955) have demonstrated that palatal growth is based on sutural growth and appositional growth as well as resorptive changes (Björk and Skieller, 1977). Björk and Skieller (1977) also showed that the position of the pterygopalatine canal in lateral radiographic profiles remains unchanged in relation to the sella turcica during growth.

In studies of prenatal palatal growth, Kjær (1989, 1990) has shown that the initial prenatal ossification of the palate takes place in close proximity to the maxillary nerves, the nasopalatine nerves, and the greater palatine nerves. After the formation of the osseous palate, the greater palatine foramen is located between the palatal bone

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and the maxillary bone. The incisive foramen is located between the maxillary bones. Silau et al. (1994) have shown that the prenatal growth in the transverse palatine suture appears as differential growth.

On the basis of these observations of the prenatal relationship between nerve and bone tissues and the postnatal stability in the location of the pterygopalatine canal in relation to the sella turcica, the present investigation was undertaken to determine how various parts of the osseous palate contribute to the overall postnatal lengthening of the palate, to study the growth in width of the palate; and to investigate developmental changes in the position of the dentition by using the nerve canal openings in the bony palate as reference points.

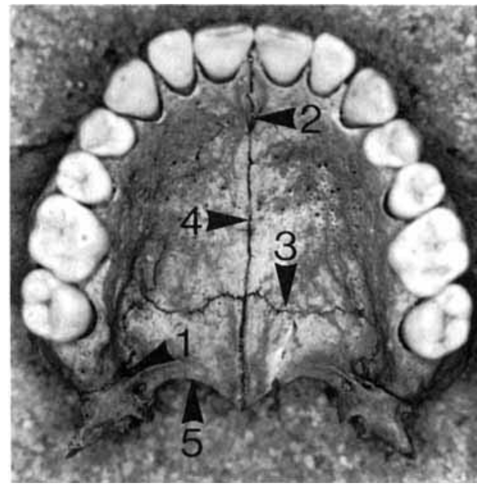

Fig. 1. Photograph of an adult human maxilla in the occlusal view. Arrowheads indicate 1) right greater palatine foramen; 2) incisive foramen; 3) transverse palatine suture, left side; 4) intermaxillary suture; 5) posterior border of the right palatine bone.

MATERIALS AND METHODS

The cranial material used in this study derives from an archaeological excavation of a large medieval cemetery, located under the present main street of the town of Holbæk in Zealand, Denmark. The excavation was undertaken in 1986 under the leadership of Curator Else Asmussen, M.A. According to the archaeologists, the church was founded about A.D. 1200, and was subsequently in use for 300 to 400 years. The excavated part of the graveyard covered an area of 450 m^2.

The skeletal remains of 673 individuals (259 children and 414 adults) were recovered, constituting the largest churchyard excavation in Denmark representing a normal medieval population from a provincial town (Koch, 1986). A systematic anthropological examination, including sex determination, carried out by J.B. Jørgensen (personal communication) showed that the individuals are of Nordic type (Brøste et al., 1956; Sellevold et al., 1984). The investigation revealed no sign of specific pathological bone changes, but did show arthritic changes, increasing with age, comparable to those seen in other such skeletal collections. The sex and age distributions are normal compared with other Scandinavian medieval populations (Sagne, 1976).

It turned out that skeletons from 22 children and 17 adults had intact maxillas (Fig. 1) and were therefore selected for study. The adults included 7 males, 6 females and 4 of indeterminate sex. The sexes of the children are unknown. Data were not partitioned according to sex. The ages of the crania were evaluated from tooth wear, tooth eruption, and epiphyseal closures in the postcranium. The age distribution of the adults is diagrammed in Figure 2.

After ages were determined for the cranial material, it was grouped into the following nine dental stages as defined by Björk et al. (1964): DS01, deciduous teeth erupting (not yet in occlusion); DS02, deciduous teeth completely erupted (in occlusion); DS1, permanent incisors erupting; DS2, permanent incisors completely erupted; DS3, permanent canines and premolars erupting; DS4, permanent canines and premolars completely erupted; DSM1, first permanent molar completely erupted; DSM2, second permanent molar completely erupted; DSM3, third permanent molar completely erupted. According to Helm and Seidler (1974), average ages of eruption of the permanent teeth are as follows: DS1, 6 years; DS2, 8–8.5 years; DS3, 9–9.5 years; DS4, 12–12.5 years; DSM1, 6 years; and DSM2, 13–13.5 years. Photographs of all the maxillae were taken

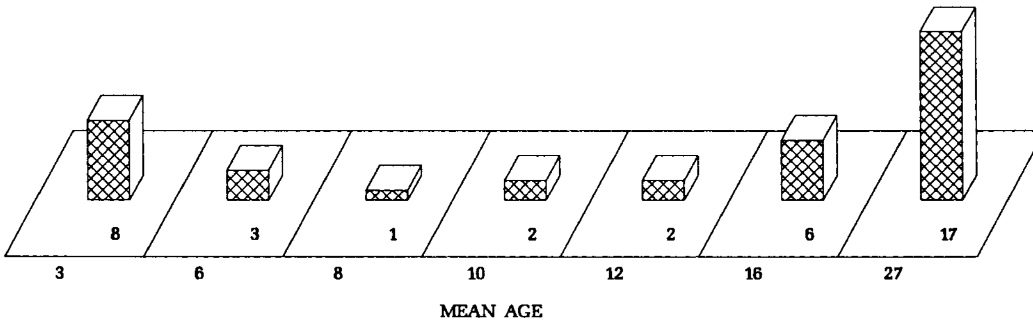

Fig. 2. Frequency bar graph of the age distribution of the children. The adults are represented in mean age block 27.

in order to project the concave palate onto a plane surface upon which exact measurements could be made (Fig. 1).

The crania were placed in sand and oriented with the occlusal plane of the teeth in the horizontal position, using a spirit level resting upon a plexiglas plate placed above the occlusal plane of the teeth. The photographs were taken with an Olympus OM-2N camera in a fixed position, on Kodak TMX 100 ASA film, routinely processed. Paper prints were produced and all measurements were made using Mitutoyo 505-666, D15F slide calipers.

Four reference lines and three points (Fig. 3) were marked on every photograph for use in measuring longitudinal growth of the palate. Line A is the tangent to the posterior edges of the greater palatine foramina. Line B is the minimal distance between the upper canines. Line C is drawn parallel to B through the posterior edge of the incisive foramen. Line D is drawn perpendicular to C from the incisive foramen to the back edge of the palate. Point s on each side is the most lingual point on the sulcus between the two lingual cusps of the first molar. Point m on each side is the midpoint of the distance from s to the median palatine suture. The mean distance from the second deciduous molars to the sulcus on M^1, calculated from those DS02 cases where M^1 was visible, was used to construct point m in those DS02 cases (50%) where M^1 was not visible. Point ts is the intersection of the transverse palatine suture with a line drawn through m parallel to D.

The following distances (Fig. 4) were measured: 1) canal-related palatal length (INCPAL), the average of the two lines drawn from C perpendicular to A at the posterior edges of the greater palatine foramina; 2) canal-related maxillary length (INCTRV), the average of the distance from C to left and right *ts*; 3) anterior palatine bone length (TRVPAL), the average of the distances from A to left and right ts; 4) posterior palatine

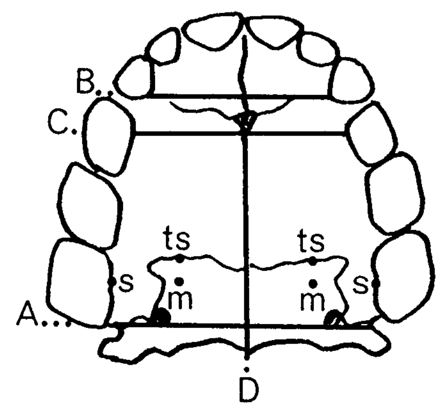

Fig. 3. Sketch of a human maxilla illustrating reference lines and points used in this study. Line A is the tangent to the posterior edges of the greater palatine foramina. Line B is the minimal distance between the upper canines. Line C is the line parallel to B on the posterior edge of the incisive foramen. Line D is drawn perpendicular to C from the incisive foramen to the back edge of the palate. Point s on each side is the most lingual point on the sulcus between the two lingual cusps of the first permanent molar. Point m on each side represents the midpoint of the distance from s to the median palatine suture between the first permanent molar and line D. Point ts on each side represents the intersection of the transverse palatine suture with a line drawn through m parallel to D.

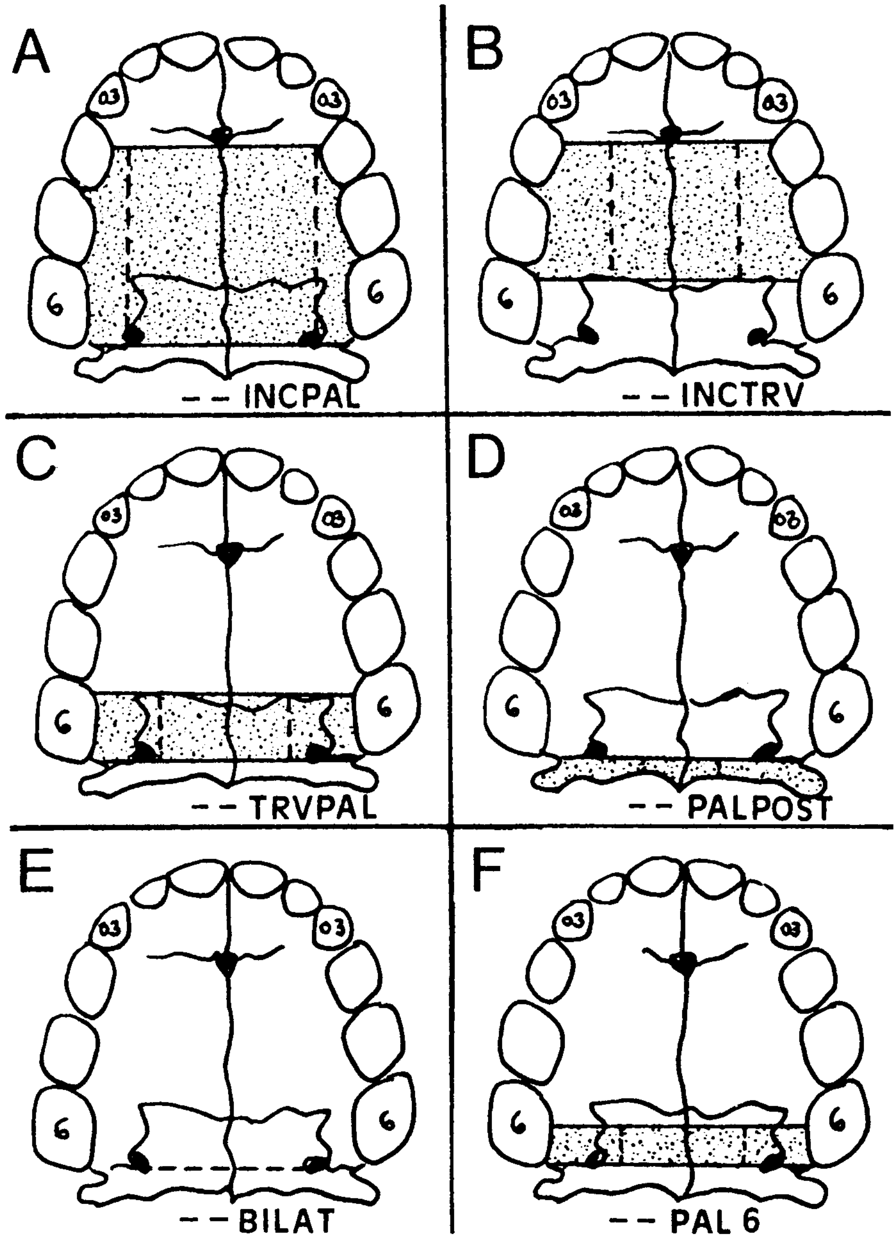

Fig. 4. Sketches of distances measured, indicated by dots. **A:** The canal-related palatal length (INCPAL). **B:** The canal-related maxillary length (INCTRV). **C:** The anterior palatine bone length (TRVPAL). **D:** The posterior palatine bone length (PALPOST). **E:** Palatal width (BILAT). **F:** Location of the first permanent molars (PAL6).

bone length (PALPOST), the average of the minimal distances from A to left and right palatine bones; 5) interpalatine width (BILAT), the maximum distances between the edges of the left and right greater palatine foramina; 6) M^1 position (PAL6), the mean of the distances from the left and right s points to A.

Statistical evaluation

A conversion factor was established for each individual, so that the measurements on the photograph corresponded with the actual measurements on the jaws. All the calculations were made on the basis of these corrected measurements.

The statistical evaluation of the results was based on the measurements of the palate, related to the dental stages. For each dental stage a mean age was determined for further calculations. Rather than making simple comparisons of successive age groups, the pattern of growth was described through the use of a flexible three-parameter family of functions, defined as:

$$h(\text{age}) = a_0 + (a_{adult} - a_0)(1 - \exp(-r\ \text{age}))$$

where a_0, a_{adult} and r denote parameters (different for each measurement) respectively representing the intercept (level at age 0, a_0), asymptote (adult level, a_{adult}) and rate of approaching asymptote, r (Ratkowsky, 1983). For each measurement, the parameters were estimated by the least-squares method, ignoring uncertainty in the age determination. $P < 0.05$ was considered to be statistically significant.

RESULTS

Growth of the palate in length

The canal-related palatal length showed statistically significant increases as the dental stage increased. The measurements of the maxillary length (INCTRV) and the anterior palatal length (TRVPAL) both showed significantly increasing values according to increasing dental stage (age) (Fig. 5). The distance from the greater palatine foramina to the posterior margin of the palatine bone (PALPOST) did not increase significantly with age. Thus, the growth which occurs in the hard palate is characterized by growth taking place anteriorly to the greater palatine foramen.

Growth of the palate in width

The distance between the right and left greater palatine foramen (BILAT) increased as the dental stage increased. Growth of the palate in width seems to occur evenly throughout the growth period, and this growth apparently continues into adult life (Fig. 5).

Location of the dentition

The distance between the first permanent molar and the greater palatine foramen (PAL6) increases with increasing age, which means that the tooth and the surrounding bone is moved forwards in relation to the palatine foramen during growth (Fig. 5).

Statistical evaluation

Despite a large interindividual variation within each age group, all measurements but one showed clear evidence of dimension increasing with age (Fig. 5). The class of functions described above gave an adequate fit for all measurements, meaning there was no systematic departure from the model (Ratkowsky, 1983).

However, for the measurement of palatal width (BILAT), the growth was close to linear, with an estimated increase of 0.204 mm (0.037) per year. For the measurements of the palatal length posterior to the greater palatal foramen (PALPOST), significant growth was not found ($P = 0.61$) for a test of zero slope in a simple linear regression. The estimated parameters with corresponding standard errors are shown in Table 1. Similarly, for the ratio INCPAL/INCTRV (total length/maxillary length), the estimated increase was 0.0022 (0.0010) per year.

DISCUSSION

This study shows that the growth which takes place in the osseous palate from childhood to adulthood occurs anterior to the greater palatine foramen, supporting the findings of Björk and Skieller (1977) concerning the stability of the pterygopalatine fossa. The distance in the sagittal plane from the incisive canal to the transverse palatine suture, as well as the distance from the transverse palatine suture to the greater palatine foramen, accordingly show how much the maxillary component and the palatine bone component, respectively, contribute to the growth of the palate in length. Silau et al. (1994) have previously reported that in the prenatal period there is differential growth of the transverse palatine suture

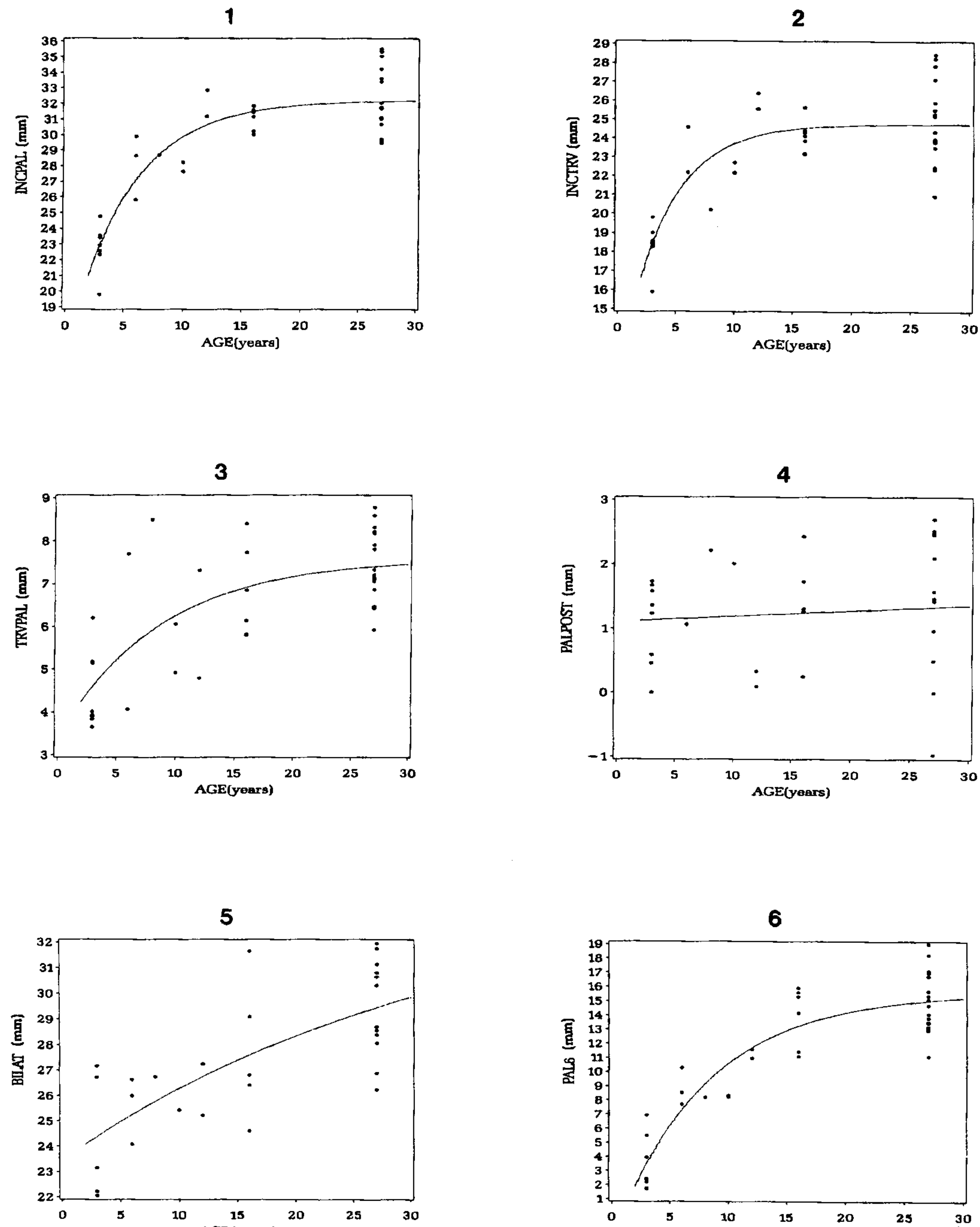

Fig. 5. Values of metric variables plotted against estimated ages. The canal-related palatal length (INCPAL) **(1)**, the canal-related maxillary length (INCTRV) **(2)**, and the anterior palatine bone length (TRVPAL) **(3)** increased significantly with age. The posterior palatine bone length (PALPOST) **(4)** did not increase significantly with age, indicating that growth in the hard palate takes place anterior to the greater palatine foramen. The interpalatine distance (BILAT) **(5)** increased linearly with age. The M^1 position (PAL6) **(6)** increased with age.

TABLE 1. Estimated length values (mm)

Variable	a_0	a_{adult}	r
INCPAL	15.58 (2.69)	32.20 (0.45)	0.196 (0.047)
INCTRV	11.13 (4.58)	24.75 (0.42)	0.257 (0.105)
TRVPAL	3.34 (1.01)	7.58 (0.50)	0.116 (0.066)
PAL6	−2.04 (1.98)	15.59 (0.82)	0.126 (0.031)

INCPAL, the canal-related palatal length; INCTRV, the canal-related maxillary length; TRVPAL, the anterior palatine bone length; PAL6, distance from the first permanent molars to the greater palatine foramen. a_0, level at age 0; a_{adult}, estimated value at adult age; r, rate of approaching asymptote. Standard errors in parentheses.

in the sagittal plane. It is well-known from the literature that the human osseous palate grows several centimeters in length postnatally, but histological and radiological investigations show that there is very little appositional and resorptive remodelling on the anterior surface of the maxilla (Björk, 1955; Björk and Skieller, 1977; Enlow and Moyers, 1971; Melsen, 1975; Korn and Baumrind, 1990; Iseri and Solow, 1990). Recent studies of palatal growth in various primates show that there is a substantial local growth in the anterior part of the palate (Corner and Richtsmeier, 1991, 1992). However, to compare these results with the findings of this study, more information is needed about growth in the incisive suture.

This study demonstrates that the growth increment in millimeters in the canal-related maxillary length (INCTRV) is more pronounced than the growth increment in the anterior palatine bone length (TRVPAL) (Fig. 5). This fact indicates that the differential growth of the bony palate observed prenatally (Silau et al., 1994) may continue after birth.

A schematic sagittal view of the palatal bone is shown in Figure 6, illustrating the direction of the incisive canal, the transverse palatine suture and the pterygopalatine canal. The implied pattern of palatal growth is partly described prenatally by Njio and Kjær (1993). The incisive canal has an inclination in the sagittal plane that corresponds to the downward and forward growth that takes place in the maxilla from childhood to adulthood (Enlow and Bang, 1965). This inclination shows that the incisive foramen is similarly displaced during growth. The figure also illustrates the fact that the transverse palatine suture is orientated in a way that corresponds with the direction of for-

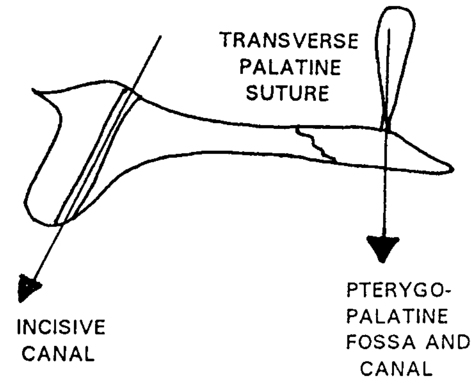

Fig. 6. Schematic drawing of the maxilla in the sagittal plane, indicating the (midsagittal) incisive canal and the (parasagittal) pterygopalatine fossa and canal. The direction of the incisive canal corresponds to the downward and forward growth of the maxilla. The direction of the transverse palatine suture permits displacement of the maxillary and palatal bones during growth. The pterygopalatine fossa (and the associated canal) is seen as an approximately vertical structure, indicating that this fossa does not undergo anterior displacement during growth.

ward and downward growth in the maxilla. When appositional growth occurs on the inclined suture surfaces, the maxilla is transported downwards and forwards in a direction corresponding to that of the incisive canal. The pterygopalatine fossa is seen as an approximately vertical structure, which seems to be related to the fact that this fossa and the contained pterygopalatine ganglion do not change location to any marked extent during growth (Fig. 6).

The increase in width of the maxilla seems, according to this study, to continue after growth can be expected to have ceased. A recent study of the dimensions of the mandible at various stages of development, carried out by Baumrind and Korn (1992), shows with the aid of metal implants that there is a small, but measurable, increase in the width of the mandible even after growth seemingly has finished in the symphysis menti. It is reasonable to suggest that there is a connection between the increases in width of the mandible and of the maxilla as long as the two dental arches are in harmonious occlusion, probably caused by the chewing function.

As previously noted, the canines are con-

sidered to be stably localized in the maxilla in relation to the incisive suture during growth (Sejrsen et al., 1993). In connection with the growth and eruption of the permanent dentition, more space is needed for the new incisors. This growth of the anterior maxilla seems to take place in the premaxillary area, and the incisive suture has a decisive role to play in this process (Njio and Kjær, 1993; Sejrsen et al., 1993).

As the present study has shown that the distance from the greater palatine foramen to the posterior margin of the palatine bone is constant at the various dental stages, apposition of new bone on the posterior part of the bony palate can hardly play any important role in increasing the space available for the developing maxillary premolars and molars. This space therefore has to be obtained by growth in the transverse palatine suture. Björk's studies showed that the apposition which takes place at the maxillary tuberosity is limited compared to the sutural growth (Björk, 1964).

The present study has shown that during growth the maxilla, including the maxillary teeth, is displaced mesially. The measurements made in this study may serve as standard jaw measurements in later evaluation of jaw material with pathological changes. The size standards in the present investigation may also be valuable for the evaluation of the development of the jaw skeleton under normal and pathological dental conditions and in cases of tooth agenesis.

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